ORIGIN AND EVOLUTION OF THE UNUSUAL OBJECT 1996 PW Paul R. Weissman[1] and Harold F. Levison[2], [1]Jet Propulsion Laboratory (Mail stop 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109, pweissman@issac.jpl.nasa.gov) [2]Southwest Research Institute (1050 Walnut, Suite 429, Boulder, CO 80302, hal@gort.space.swri.edu)

The unusual object 1996 PW was discovered August 9, 1996 by an automated search camera operating from Mt. Haleakala Observatory in Hawaii.[1] Orbital elements determined for 1996 PW are: a = 322 AU, q = 2.54 AU, e = 0.992123, i = 29.9°, and period ≈ 5,800 years.[2,3] The only objects discovered in such eccentric orbits to date are active long-period comets. However, physical observations have failed to detect any evidence for cometary activity in 1996 PW.[4-7] The object is described as red in color, similar to S and D asteroids and cometary nuclei. Assuming a typical cometary albedo of 0.04, 1996 PW is ~15 km in diameter; for a stony asteroid albedo of 0.15, its diameter is ~8 km.

Speculation has focussed on whether the object is a dormant or extinct cometary nucleus, or an asteroid, and whether it is evolving into or out of the planetary system. We performed a series of dynamical simulations and calculations to test each of five different hypotheses. First, we assumed that 1996 PW had come from the Oort cloud and estimated its dynamical age using a Monte Carlo simulation of planetary perturbations.[8] The model assumed that objects random walked in orbital energy, 1/a, and could be lost by ejection to interstellar space or by being returned to the Oort cloud (a > 10^4 AU); no physical loss mechanisms were included. Results for 10^6 simulated objects yielded a sharply peaked dynamical age distribution with a maximum at only 5 returns, and a long tail. The median number of returns was 24, and 95% of the comets with orbits similar to 1996 PW had ages of 368 returns or less; 99% had made less than 750 returns.

How long then does it take a comet to evolve physically to a dormant or extinct state? Estimates of the physical lifetimes of comets as active bodies vary considerably. As a **minimum,** one can consider periodic comets Encke and Halley, which have been observed on 56 and 30 returns, respectively.[9] Estimates of the age of Comet Halley range from 2.3 x 10^4 to over 2 x 10^5 years, equal to 300–2,600 returns at its current orbital period.[10,11] The sublimation lifetime for a 1 km radius, low-albedo water ice sphere with a perihelion distance similar to that of 1996 PW is >5,000 returns.[12] Dynamical studies of the evolution of Jupiter-family comets suggest a median physical age of 12,000 years as active comets, or typically about 1,500 returns.[13] Given these results, it appears extremely unlikely that 1996 PW could have evolved to a dormant or extinct state in the median age of only 24 returns, and unlikely at the 95% level that it could have done so in any reasonably probable age of a few hundred returns.

Could 1996 PW be an asteroid which was placed into the Oort cloud and which has now been thrown back into a planet-crossing orbit? Although there has been some speculation on asteroids being placed in the Oort cloud,[14] the problem has never been pursued in detail. However, new dynamical simulations by Levison and Duncan (personal communication) find that 8% of the material initially in orbits between Jupiter's orbit and the 2:1 mean-motion resonance at 3.28 AU (roughly the outer edge of the main asteroid belt) are ejected to bound orbits with a > 10^4 AU. Given an initial surface density of condensed solids, i.e., rocky/carbonaceous bodies, in the solar nebula of 30 g cm^{-2} at the Earth's orbit, and assuming the surface density varied as $r^{-3/2}$ through this region, there would have been 1.6 Earth masses ($M_\oplus$) of rocky/carbonaceous bodies between 3.28 and 5.2 AU. If 8% went into the Oort cloud, then we would expect 0.13 $M_\oplus$ of asteroids in the Oort cloud. This compares with an initial mass of ~16 $M_\oplus$ in the outer, dynamically active Oort cloud.[15,16] Thus, 0.8% of the objects from the Oort cloud may be asteroids rather than comets. This is likely a conservative number since considerably more rocky objects must have been ejected from orbits interior to 3.28 AU during the dynamical clearing of the planetary zones.

Given the ratio found above, and assuming that there are 10^{12} comets in the Oort cloud and that the size distributions are similar, there are -8 x 10^9 asteroids in the outer Oort cloud. The estimated flux of long-period comets at the Earth's orbit is ~10 yr^{-1} (ref. 15), suggesting at least 25 yr^{-1} at 2.5 AU, the perihelion distance of 1996 PW (again, an under-estimate because the cometary perihelion distribution increases with heliocentric distances). This would then predict a flux of at least 0.2 asteroids from the Oort cloud per year. This number is also highly conservative since most long-period comets discovered are brighter than 17th magnitude (the visual magnitude of 1996 PW), and are often discovered as a result of outbursts which suddenly raise their brightness considerably.

Alternatively, 1996 PW might be an extinct ecliptic comet, a main belt asteroid, or a Trojan asteroid currently evolving out of the planetary system. We have estimated the total population of such objects in the solar system and studied their dynamical evolution. We find that less than one object is expected to exist in each of these classifications in an orbit similar to that of 1996 PW (a = 100--500 AU and q < 3 AU).[13,17-19] If one considers that 17th magnitude objects such as 1996 PW have been discovered only during the past 50 years, then there is less than a 1% probability that one of these objects might be passing through perihelion during this period. This thus seems an unlikely origin for 1996 PW.

We conclude that the most likely scenario for the origin of 1996 PW is that it is one of many asteroids that was ejected to the Oort cloud, probably early in the solar system's history during the clearing of the interplanetary zones. The object has now been returned to the planetary region by the same combination of stellar and galactic perturbations that feed long-period comets in towards the Sun.

What is the future for 1996 PW? We integrated 24 test particles with initial orbits similar to 1996 PW, both forward and backward in time, until the objects were either ejected from the planetary system or perturbed to semimajor axes > 10^4 AU, allowing them to be recaptured to the Oort cloud. The median dynamical age was 200 returns with a typical lifetime of 7 x 10^5 years. The object could conceivably become an Earth-crosser late in its dynamical evolution.

Given the results above, we suggest that 1996 PW may be only the first detected member of a likely population of asteroids which reside in the Oort cloud, some of which may now be passing through the planetary region on highly eccentric orbits. We hope that the discovery of this new class of objects will increase as additional automated search programs such as the one on Mt. Haleakala come on line.

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